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The Star Excursion Balance Test: A predictor of lower-extremity injury risk and a measure of an athlete's readiness to return to play

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Abstract:- Lower extremity musculoskeletal injuries are commonly predicted, prevented, and rehabilitated using dynamic balance as a criterion. Dynamic balance is used as a functional performance assessment to determine injury risk. An increased risk of injury has been associated to a lack of dynamic stability and a balance deficit. The star excursion balance test is a functional test utilized by sports scientists and physical therapists to assess the neuromuscular control that determines the athletes' dynamic balance. The star excursion balance test is a valid and reliable tool for assessing or predicting the risk of musculoskeletal injuries, lower leg muscle strength, coordination, balance, flexibility, co-contraction, passive stiffness of the lower limbs, and lumbopelvic stability. This review aimed to enlighten the need for and importance of the star excursion balance test in predicting the risk of injuries in the lower leg and assess improvements in dynamic balance following training for rehabilitation purposes and return to play after injury. A comprehensive search has been made to complete this review. Several factors have been identified as having an impact on the performance of the star excursion balance test. The present review provides an insight into sportspersons, coaches, fitness trainers, sports scientists, and physical therapists with useful information regarding the importance of functional testing (star excursion balance test) as a screening tool prior to participating in any sporting activities at any level to avoid the risks of lower leg injuries and can assist in the return-to-play decision-making process.

Keywords*: Prediction 1; Injury 2; SEBT 3; Return to Play 4; Athletes readiness 5.*

1. Introduction

Sports injuries are a common occurrence and concern for those participating in and practicing sports. Distinguished rates of sports injuries have been reported according to the levels of participation. Sports injuries have a physical, psychological, and financial burden on the sportsperson, family, institutions, and organizations. Understanding risk factors for sports injuries and their relationship is a key component for preventing future injuries among athletes. Several research has been attempted to determine factors associated with the risk of injuries, which is important when developing injury prevention and risk mitigation strategies. A literature review on sports injuries concluded that injury prevention had become a sports population health priority [1]. Early specialization and poor sports participation management increase the risk of injury and have long-term health implications [2].

Following an injury, identifying functional performance deficiencies, as described by return-to-sport criteria, reduces risk factors of sports injuries and imparts instructions for safe participation in sports [2,3]. Sportspersons

with a history of injuries lack the necessary neuromuscular control, balance, proprioception, and muscular strength to participate safely in sports [4,5]. Manske and Reiman stated that functional performance tests/measures are used to evaluate and quantify specific movements in sports and fitness [6]. The clinician and sports coaches use functional performance tests as a preparticipation screening tool. In 2014, the American College of Sports Medicine Summit reviewed and examined the effectiveness of functional movement tests in determining musculoskeletal injury risk. An organized approach to movement evaluation has been suggested as an effective strategy for injury prevention [7]. Many factors of lower-extremity function are included in functional performance assessment, involving neuromuscular coordination, dynamic stability, and muscular strength [8]. The star excursion balance test is a functional performance assessment tool used as a clinical tool to evaluate neuromuscular control deficits and dynamic stability to predict injury risk and a way to evaluate an athletes' readiness to return to play after an injury [9].

2. Validation and reliability:

The star excursion balance test was initially described by Gray [10]. The star excursion balance test is a functional test evolved from lower-limb rehabilitation exercises. Since the beginning, the star excursion balance test has been extensively studied in the scientific literature for its effectiveness in (a) assessing dynamic postural control of the lower leg [11], (b) identifying functional deficiencies during the return to sport phase, and (9), (c) identify sportsperson who are at risk for sports injuries [12]. According to Hegedus et al. in their systematic review, only the star excursion balance test has shown consistent value for identifying higher injury risk among athletic populations across several functional assessments [13]. The first research literature on the star excursion balance test's reliability was published in 1998 [14]. In healthy young adults, Hertel et al. established intertester, and intratester reliability (interclass correlation coefficient 0.81 - 0.96) from all eight reach directions of the star excursion balance test. These reach directions included anterior, lateral, medial, posterior, anteromedial, anterolateral, posteromedial, and posterolateral [15]. The star excursion balance test's four diagonal reach directions (anteromedial, anterolateral, posteromedial, and posterolateral) were reported to estimate test-retest reliability. Intratester reliability estimates (ICC) for the different directions ranged from 0.67 to 0.87 [14]. Recent evidence demonstrates that the star excursion balance test is highly reproducible.

The star excursion balance test is, without a doubt, a reliable and valid instrument for testing dynamic stability deficits in athletes with lower extremity injuries such as ankle sprain, knee ligament injuries, and hip injuries [16]. The use of the star excursion balance test is advantageous in detecting athletes who may be at risk to injury as a result of inadequate balance control [13]. Some investigators revealed that the practice trials before actual measurement affect the star excursion balance test performance. Participants performed three trials in each direction on day 1. while on day 2, they performed 12 trials in each direction. The intertester reliability estimate for different directions on day 1 was from 0.35 to 0.84, while on day two was from 0.81 to 0.93. The investigators conclude that participants should complete six practice trials in each direction [14]. After four trials among healthy athletes, Munro and Herrington found that the star excursion balance test had high reliability (ICC = 0.84-0.92) [17], which was in line with earlier studies on reliability [14–16].

Researchers have also discovered that not all eight directions are required to obtain useful information from the star excursion balance test assessment. All eight lines had a significant degree of shared variance, indicating that an individual's ability to reach in one direction was strongly correlated with his or her ability to reach in another direction [18]. This has been mentioned as test redundancy. Because of this knowledge, the test has been shortened to three directions: anterior, posterolateral, and posteromedial – and this test can be referred to as the modified star excursion balance test or Y balance test. This modification drastically decreases the time as the star excursion balance test is taken. To improve the efficacy of the star excursion balance test, Plisky et al. introduce a ready-to-use commercial product – the Y Balance Test [19]. This product consists of three pieces of polyvinyl chloride pipe extended in the anterior, posterolateral, and posteromedial reach directions from a stance platform. Each pipe is labelled in a 5 mm increment distance. The participant uses the foot of the extended leg to push a target (reach indication) along the pipe. After the test, the target remains over the tape for easy measurement. The intratester and intertester reliability ranged from 0.85 to 0.89 and 0.97 to 1.00, respectively [19].

3. Testing Protocol:

The star excursion balance test is one such tool that has acquired prominence in clinical and research contexts. The test started with the athlete stand on one leg with the most distal portion of the big toe in the middle of eight diagonal lines that intersected at a midpoint and kept the hands on the hips. The test consists of balance on one leg while doing squats, and the non-stance leg is used to reach the maximum to touch a location on the ground along one of eight diagonal lines; each line intersects at 45 degrees [12]. Each reaching direction has unique challenges and combines frontal, sagittal, and transverse movements. Concerning the stance limb, the reaching distance direction is termed anterior, medial, lateral, anteromedial, anterolateral, posteromedial, and posteromedial [20]. The participant extends his reaching leg as far as feasible along each line. The extending leg returned to its original position in the middle of eight diagonal lines. The same process repeats while standing on another leg. The highest reaches distance was measured by marking tape measure with erasable ink at the spot where the big toe reached. Three trials should be conducted, and the maximum reach distance of three trails in each direction should use for further analysis. If the participant (1) does not maintain a unilateral stance, (2) lifts or moves the stance foot away from the grid, (3) touches the ground with the reaching foot, or (4) does not restore the reaching foot to its initial position, the test will be repeated and discarded [21]. The star excursion balance test requires a high level of coordination, balance, and strength, and it can be challenging for athletes who are recovering from an injury. The test should be performed under the supervision of a trained professional who can provide guidance and ensure safety. Standardized oral instructions might be imparted to the participants during the test.

The modified star excursion balance test is a shortened alternative to the star excursion balance test [22,23]. Many studies have shown that star excursion balance tests can be simplified using only three reaching lines or directions: anterior, posterolateral, and posteromedial [12,18,24]. It has been demonstrated that there is a link between posterolateral reach and flexor, extensor, and abductor hip strength and anterior reach and flexor and extensor hip strength [25]. The modified star excursion test measures dynamic stability, flexibility, muscle strength, co-contraction, passive stiffness of the lower leg, and lumbopelvic stability [23]. This test is performed while the participant keeps one leg stance at the point of intersection of the three lines; Each line intersects with other lines at 1350 in the marked anterior, posteromedial, and posterolateral directions. The participants should be informed to stand with the most distal aspect of their greater toe at the intersection of the lines with barefoot or athletic shoes and lean against the line. The non-stance leg extends towards a maximum distance in the anterior, posterolateral, and posteromedial direction while holding the single-leg stance. Three trials in each direction should be conducted without failing to maintain a single-leg stance or touch the ground with the extended leg or extended leg that cannot return to the starting position. After three attempts, the assessor assesses if the participant has at least one successful test. Suppose the participant fails to complete the test in six attempts according to the given criteria. It means that he failed to reach a specific direction or has a higher risk of injury [19].

4. Scoring criteria

The maximum reach distance of three trials in every direction will be used for analysis to determine the final scores of the star excursion balance test. To get the average distance in one direction, sum the three trails and divide them by three. Get the average distance for each direction. To get the normalized value- The total reach distance is expressed as a percentage of leg length by dividing the average distance in each direction by leg length (distance between the anterior superior iliac spine and the medial malleolus) multiplied by one hundred. The performance of a participant in the star excursion balance test could be determined by using the below-mentioned equations [26].

$$\text{Average distance in each direction (cm)} = \frac{\text{Reach 1} + \text{Reach 2} + \text{Reach 3}}{3}$$

$$\text{Relative (normalized) distance in each direction (\%)} = \frac{\text{Average distance in each direction}}{\text{Leg length}} \text{ X 100}$$

$$\text{Composite reach distance (\%)} = \frac{\text{sum of the three reach directions}}{\text{3 times the leg length}} \text{ X 100}$$

These computations should be done in each right and left leg direction, giving sixteen scores per participant.

Three distinct measurements were computed to quantify the performance on the modified star excursion balance test: normalized reach distance, composite score, and leg symmetry indices. The reach distance in each direction was normalized by leg length and reported as a percentage of leg length for each limb [21]. To get the final scores of the modified star excursion balance test, the composite reaches distance could be the sum of three directions (anterior, posterolateral, and posteromedial) reach distances divided by three timed leg lengths and multiple times by one hundred [21]. Due to participants' variability in body height, the equation mentioned below must be used to normalize reach distances to lower leg length [20].

$$\text{Anterior normalized score (\%)} = \frac{\text{Mean of the three trials in anterior direction (cm)}}{\text{Tested limb length (cm)}} \text{ X 100}$$

$$\text{Normal Composite score (\%)} = \frac{\text{norm anterior (\%)} + \text{norm posteromedial (\%)} + \text{norm posterolateral (\%)}}{3}$$

The absolute difference of distances in each direction is used to calculate asymmetry between the legs; the dominant leg's value is subtracted from the non-dominant leg's value [23]. Asymmetry between legs of 4 centimetres or more in the anterior direction and a composite score of less than 94 per cent are associated with neuromuscular control defects and a higher risk of lower limb injuries [19]. Preventive exercise measures should be considered while administrating the test [21]. According to research, athletes who successfully complete the test exhibit a decreased risk of re-injury in comparison to those who do not pass the test. Therefore, the star excursion balance test can serve as a criterion for evaluating an athlete's readiness to return to play sagely. The modified star excursion balance test quickly assesses injury risk, which is essential in reducing rehabilitation time and cost.

5. Factors Affecting Performance

5.1 Gender:

Earlier studies have evaluated gender differences in the star excursion balance test performance, but the result has been inconsistent. Plisky et al. also conducted a study with seven high school basketball players: they took the star excursion balance test before the competitive season. They discovered that females with a composite reach distance score of less than 94 per cent of their leg length were also 6.5 times more likely to sustain a lower extremity injury [21]. Males have been demonstrated to reach farther in absolute reach distance to the anterior, posterolateral, and posteromedial direction than females. However, when performance was adjusted to leg length, there was no difference between the genders in any direction [20]. While in another study, findings showed that

females had a greater standardized reach distance in all directions than males [12]. Stiffler et al. investigated star excursion balance test performance between males and females, revealing that females achieved significantly higher anterior reach distance than males [28]. Females achieved an anterior reach distance of over 6 per cent than their counterparts. Furthermore, gender differences for normalized reach distance were only identified posteriorly among healthy recreational athletes and collegiate basketball players, with males reaching 5% farther than females [29].

5.2 Sports:

Star excursion balance test performance has been found to be different in different sports. Plisky et al. conducted a study with seven high school basketball players who took the star excursion balance test before the competitive season. To establish the predictive accuracy of the star excursion balance test, rates of lower leg injury were recorded and matched from the start of competitive season performance. Basketball players with an anterior right-to-left reach discrepancy of more than 4 cm were 2.5 times more likely to incur lower extremity injuries, according to Plisky et al., 2006. College football players with a normalized composite score of less than 89.4 per cent are at a higher risk of injury [30-31]. McGuine et al. studied high school basketball players during the pre-season and measured the posture stability using the star excursion balance test [32]. They identified that those with higher postural sway had to sustain ankle injury more than seven times. Bressel et al. investigate dynamic and static balance among basketball and soccer players. They discovered that basketball players had a lower composite performance on the star excursion balance test than soccer players at the collegiate level [26]. A study conducted with collegiate athletes indicated that the normalized performance of the star excursion balance test between males and females was only significantly different for soccer players. Female soccer players had significantly higher anterior reach distance than male soccer players. Male soccer players achieved a distance of almost 6 per cent lesser than female players [28]. Furthermore, Except for women golfers, women hockey players could obtain better-normalized reach distances in the posteromedial and posterolateral directions and composite scores. Additionally, the male and female participants had no significant differences in normalized asymmetry [28].

5.3 Sports Injuries:

Several studies have found severe and long-term losses in activity participation and function following anterior cruciate ligament restoration (ACLR). According to recent studies on young individuals, quadriceps strength decreased dramatically following anterior cruciate ligament replacement, with approximately 44% of the sample losing strength when they returned to sports [33]. The deficits in dynamic stability determined by the star excursion balance test have recently been discovered as a predictor of a second anterior cruciate ligament injury in young people with anterior cruciate ligament restoration after return to sports [8]. A study compared the control group's anterior reach performance with the anterior cruciate ligament restoration leg and non-anterior cruciate restoration leg. They found that the anterior cruciate ligament restoration group had a 3.36 cm difference between legs while the control group had a 4.13 cm anterior reach distance.

Further, the anterior reach distance between both legs was more than 4 cm in 33% of the anterior cruciate ligament replacement group and 38% of the control group [9]. In addition, in comparison to undamaged teenagers, young female athletes who return to sport after an anterior cruciate ligament injury have the highest percentage of reinjuries (ipsilateral and contralateral) and were at a 30-40 times higher risk of anterior cruciate ligament injury [34]. People with anterior cruciate ligament impairment exhibited significantly lower reach scores on the afflicted and unaffected leg compared to healthy controls [35]. Further research on the modified star excursion balance test in this cohort could provide information to help guide rehabilitation and return-to-sport decisions.

5.4 Limb Asymmetry:

The limb symmetry index assesses limb asymmetries, a distinctive clinical tool for assessing performance disparities between limbs. Plisky et al. investigated a study and revealed a high risk of a noncontact lower leg injury for those with more than a 4 cm difference in anterior reach distance between both legs [21]. Stiffler et al. revealed that the bilateral asymmetry predicted lower leg injuries in the anterior reach distance of the star

excursion balancing test [36]. Gonell et al. examined the side-to-side asymmetries in soccer players. They demonstrated that the risk of noncontact injuries increased 1.92 times when more than 12 cm side-to-side difference was found in the composite score of the three directions during a star excursion balance test [37]. Similarly, a study conducted with soccer players revealed a composite asymmetry score in anterior, posterolateral, and posteromedial directions greater than 12 cm. they observed those participants at high risk of injury [38]. Conversely, A study conducted with female participants to find out asymmetry between the non-dominant and dominant leg indicated about 8 per cent of the variance in total distance scores between the non-dominant and dominant leg, whereas no significant differences were found in any of the reach distances in any direction or composite score between dominant and non-dominant leg [39].

5.5 Muscular Strength:

During the star excursion balance test, the athletes must maintain single-leg support while extending their legs as far as possible in all directions. This effort needed adequate muscle strength to maintain stability in multiple joints and body segments. Earlier studies demonstrated that the support leg's hip extensor and abductor strength are correlated with the performance of the star excursion balance test in healthy participants [9,40]. Trunk muscle strength may also influence performance to maintain stability during the star excursion balance test [41]. Thorpe and Ebersole examined the isokinetic strength of recreational and collegiate soccer players and found no differences. They also discovered a low to moderate relationship between star excursion balance test results and lower extremity strength [42]. Gordon et al. investigated the relationship between the external hip rotation and lower leg balance measured using the star excursion balance test. They found that hip external rotation strength of the dominant and non-dominant leg was moderately correlated with posteromedial reach direction scores but not with composite scores [43]. Pinheiro et al. found that a deficit in the anterior reach distance in the star excursion test may result from the strength of the knee, hip flexion, and hip extensor [44]. Wilson et al. revealed a significant positive correlation between balance scores and hip muscle strength during hip extension, abduction, and external hip rotation [45]. Lower limb muscle strength (hip flexors, hip extensors, hip abductors, knee extensors, and ankle dorsiflexors) was measured in the anterior, posteromedial, and posterolateral directions as a function of reach distance. Lower leg strength (knee flexors, hip abductors, and hip extensors) and dynamic postural control in all directions were poor connections [46].

5.5 Neuromuscular control:

The neuromuscular control exercise intervention significantly improves dynamic postural control as determined by the star excursion balance test and reduces lower leg injuries. Filipa et al. discovered that eight weeks of neuromuscular control training enhanced performance in the same three directions by 1.75 per cent to 9.5 per cent in young athletes [47]. Equally, Fitzgerald et al. identify that after 12 training sessions for postural stability training, there was a 2.95 per cent to 9.4 per cent improvement in anterior, posteromedial, and posterolateral reaching distance [48]. Improved control of the centre of mass within the base of support can prevent excessive stress on the lower leg and decrease the risk of injury [49]. For trained athletes, the star excursion balance test may be an adequately comprehensive tool that can be utilized before the competition to analyze neuromuscular aspects more thoroughly [42].

Other Factors:

The star excursion balance test scores varied based on different factors. Age, sex, and sports are prominent factors affecting the performance of the star excursion balance test [28]. Grassi et al. reported that the star excursion balance test demands lower-leg muscle strength, agility, and coordination. This could improve the test's sensitivity and capacity to predict sports injuries [50]. Joint range of motion may result in poor performance of the star excursion balance test as greater knee flexion and smaller hip flexion lead to a deficit in anterior reach distance [44]. The reach distance in different directions is also affected by testing setups [51]. Gribble et al. stated that the dynamic postural control assessment utilizing the star excursion balancing test was better in the morning (10:00) than in the afternoon (15:00) and nighttime (20:00) [52]. They also insist that the researcher administer the star excursion balance test at a specific time to standardize it while administering it on different days. The core

stabilization training improves the neuromuscular system, resulting in optimal muscular balance and efficient lower leg movement during the star excursion balance test [53]. Foot placement should be considered while performing the star excursion balance test. Different foot alignment and hand positions may lead to misinterpretation of the findings, particularly the anterior reach score [54]. No significant differences between loss of arch foot and normal arch foot control in reaching distance [12]. Hegedus et al. conclude that fourteen functional performance tests are regularly used to determine the risk of injury in athletes. Only the star excursion balance test has high reliability and validity athletes' high risk of injury [13]. Another study examined the relationship between the modified star excursion balance test and lower extremity injuries in collegiate athletes for both males and females. There was no statistically significant difference in outcomes between individuals with a lower extremity injury and those without; however, certain traits within each gender may be more strongly linked to lower extremity injuries [55]. At the same time, Stiffler found that asymmetry between limbs in the anterior reach of the star excursion balance test was predictive of lower extremity injury in division I collegiate athletes [36].

6. Conclusions

The utilization of the star excursion balance test has been established as a reliable and valid tool for evaluating an athlete's capacity for dynamic balance, proprioception, and neuromuscular control. Furthermore, it has been found to be consistent in its ability to predict the likelihood of a lower leg injury. It provides objective data on an athlete's balance deficits and helps identify areas that need improvement. This review offers valuable information to sportspersons, coaches, fitness trainers, sports scientists, and physical therapists regarding the prediction and prevention of lower leg injuries. Additionally, the star excursion balance test can be used to design a customized rehabilitation program that targets an athlete's specific needs and addresses any balance deficits. Consequently, it is imperative to incorporate the star excursion balance test in the process of selecting players and within any comprehensive rehabilitation program for athletes recovering from injuries to the lower extremities.

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